Efficiency Differentials in Cotton Production: A Case from the Punjab Province, Pakistan

Muhammad Arif Watto[1][2]

[1]School of Agricultural and Resource Economics, Faculty of Natural and Agricultural Sciences, The University of Western Australia M089, 35 Stirling Highway, Crawley WA 6009 Australia

[2]Depaerment of Agricultural Extension, The University of Agriculture, Faisalabad, Pakistan

Corresponding Author:

Muhammad Arif Watto

E-mail: 20798429@student.uwa.edu.au; arifwattoo@ymail.com

Tel: +61425572555, Fax: +61-08-6488-1098

Efficiency Differentials in Cotton Production: A Case from the Punjab Province, Pakistan

Abstract

This study employs a non-parametric data envelopment analysis (DEA) approach to measure technical efficiency and the technological gaps among cotton producers in the Punjab province of Pakistan. A cross-sectional survey data from 189 cotton growers comprising 98 tube-well owners and 91 water buyers is used to estimate technical efficiency relative to a meta-frontier and group-frontiers. The mean results indicate that efficiency estimates do not differ considerably under the meta-frontier and group-frontier specifications, however, overall distribution for technical efficiency differ considerably under both estimations. Although, mean TE scores do not indicate substantial technical inefficiencies, nevertheless, only 19% of the tube-well owners and 17% of the water buyers are found to be fully efficient under the meta-frontier estimates. The group-frontier estimates suggest that relatively more number of tube-well owners and water buyers are fully efficient, suggesting that both tube-well owners and water buyers are operating under different states of technology. Second-stage bootstrap truncated regression results have policy implications to improve resource use efficiency in cotton farming.

Key Words: Technical efficiency, technology gap, cotton production, truncated regression, Punjab, Pakistan

1 Introduction

Predominant agrarian economy of Pakistan is greatly influenced by the performance of agriculture sector (Ahmad et al., 2002). Agriculture sector accounts for 21% to the country's gross domestic product and employs above 40% of the country's total labour force (Pakistan, 2011-12). Hence, improving agricultural productivity and farm efficiency are the major agricultural policy concerns in Pakistan. Cotton is one of the major agricultural export commodities for Pakistan which accounts for 6.9% to the value added in agriculture and 1.4% to the gross domestic product. Pakistan's largest exports include cotton and cotton related goods and services, which account for about 60% of its export market. In 2011, with 2.35 million tonnes of cotton production, Pakistan was ranked at number 4th in production and 3rd in consumption (FAO, 2012; Pakistan, 2011-12). Figure 1 shows position of Pakistan amongst major cotton producing countries.

[Insert Figure 1]

Despite such an important role in national economy, cotton production has been facing widespread stagnation in per hectare yields. Based on per hectare yield, Pakistan is ranked at number 20th in the world cotton production. During the last two decades, cotton production in Pakistan has been confined to10 to 12 million bales while consumption has doubled from

5.7 to 11.5 million over the same period (USDA, 2012). Resultantly, cotton exports are in gradual decline. Once, one of the major cotton exporting countries, Pakistan imported 2400 bales of cotton in 2012 while Pakistan could hardly manage to export 500 bales. In recent years, gap between cotton production and domestic consumption has gone up to 0.31 million tonnes annually (Pakistan, 2011-12; USDA, 2012). Hence, any policy intervention improving cotton production, marketing, import and exports would have serious implications for the national economy. Figure, 2 and 3 represent historical trends in cotton exports and imports of Pakistan.

[Insert Figure 2 &3]

Pakistan Central Cotton Committee (PCCC) aims to increase cotton production by 40-60% as a national strategy to achieve the 19.1 million bales target by 2015. Major components of this strategy include: 1) to increase area under cotton cultivation, 2 :) to encourage adoption of genetically modified cotton varieties, 3 :) to improve production technology, 4 :) to subsidize fertilizers and 5 ;) to manage integrated pest management (PCCC, 2008). While improving cotton productivity is a major policy goal in Pakistan, the efficient use of inputs including water is indispensable in agricultural production. Presently, Pakistan is facing the most striking challenge of water scarcity in the world. Hence, pressure is increasing to improve agricultural productivity and farm efficiency to make better use of scarce water resources. Although, stagnant cotton production have been subject to various factors such as geographic and climatic but, the farm management practices and inefficient resource utilization have a major role in low productivity (Khan and Iqbal, 2005). Due to the scarcity of new arable land and surging water scarcity, the only viable solution to increase cotton production could bring through improvements in per hectare yield either by efficient use of inputs or adoption of improved technology.

Several studies have focused on efficiency measurements of cotton production in Pakistan (Abedullah et al., 2006; Hussain et al., 1999; Khan and Iqbal, 2005; Shafiq and Rehman, 2000),however, none of the studies have measured the performance of farms across different groups which differ in resource ownership and also do not capture the technological gaps between these groups.

Given the above backdrop, this study measures the technical efficiency and also examines the differences in production efficiency among cotton growers in the Punjab province, Pakistan. This study uses a randomly selected sample of 189 groundwater-irrigated cotton-growing farmers, including 98 tube-well owners and 91 water buyers (non-owners).We assume that tube-well ownership can cause efficiency differences among the tube-well owners and water buyers. Although, water buyers have the opportunity to use groundwater but, they do not have surety of getting water for irrigation over the spatio-temporal crop water requirements. Sometimes, water buyers need to wait for few days to get water. Based on this technological difference, tube-well owners and water buyers can be grouped into different categories operating under different states of technology; hence, estimating a separate frontier for each group would help to reveal the difference between the technology and efficiency effects (Battese et al., 2004; O'Donnell et al., 2008). The study uses data envelopment analysis approach (DEA) to compute technical efficiencies relative to a meta-frontier and group frontiers. In addition, a second-stage bootstrap truncated regression method is used to identify the factors influencing technical efficiency in cotton cultivation.

The remaining paper is organised as follows. The next section describes the methodological framework for the efficiency measurements and the theoretical background of DEA. The methodological section describes an input-oriented DEA model under variable returns (VRS) to scale to compute technical efficiency. Section 3 describes the data and principle features of the study areas. The results are presented in Section 4. The final section provides conclusions and policy implications.

2 Methodological Framework

2.1 Efficiency Measures

Efficiency of any decision making unit (*DMU)* is measured either by a parametric method, such as stochastic frontier analysis (SFA), or by a non-parametric measure, such as data envelopment analysis methods (DEA).The parametric measures (SFA) estimate efficiency statistically, while the non-parametric approach (DEA) constructs a linear piecewise frontier to describe the relationship between inputs and outputs. Several studies e.g., (Alene and Zeller, 2005; Kalyan Chakraborty et al., 2002; Thiam et al., 2001; Wadud and White, 2000) found the comparative results of both approaches to be highly correlated. The choice of any particular approach, however, depends on the objective of the research, the type of production unit and the data available (Wadud and White, 2000). Both approaches have several advantages and disadvantages over each other. The major advantage of data envelopment analysis is that it does not assume any a priori functional relationship between the inputs and outputs.

2.1.1 Technical Efficiency Measurement

Let us consider *n DMUs* that produce an output *Y* using input *X*. *X* is a $n \; x \; m$ matrix of inputs (*m*=1, 2...6), and *Y* represents an $n \; x \; s$ output row vector (*s*=1, i.e., wheat yield). For DMU_{j_o}, the input and output data are represented by column vector x_{j_o} and row vector y_{j_o}. Following

(Banker et al., 1984), to compute technical efficiency under VRS for DMU_{j_o}, the following linear programming problem has solved for:

$$\mathrm{Min}_{(\lambda,\theta)}\ \theta$$

(1)

Subject to:

$$\sum_{j=1}^{n} \lambda_j Y_j - y_{j_o} \geq 0,$$
$$\sum_{j=1}^{n} \lambda_j X_j - \theta x_{j_o} \leq 0,$$
$$\sum_{j=1}^{n} \lambda_j = 1,$$
$$\lambda_j \geq 0$$

where θ is a scalar, and λ is an $n \times 1$ vector of inputs and output weights and $\sum_{j=1}^{n} \lambda_j = 1$ is a convexity constraint to compute technical efficiency under *VRS* specification.

2.1.2 The Technology Gap Ratio

To determine the impact of tube-well ownership on farm efficiency estimates, this study estimates efficiencies relative to a meta-frontier and group-specific frontiers for tube-well owners and water buyers.O'Donnell et al. (2008) explained that a meta-frontier model envelops various group frontiers. The estimation of a meta-frontier offers to compare efficiencies from group frontiers that enable us to calculate the technology gaps between the meta-frontier technology and group-frontier technology. The meta-frontier concept was formally introduced by Battese and Rao (2002) and Battese et al. (2004) for a stochastic frontier and was extended by O'Donnell et al. (2008) to DEA. In DEA, group-frontiers are constructed by estimating a DEA model for each group, and the meta-frontier is then estimated by pooling all observations for all groups. The technology gap ratio (*TGR*), according to O'Donnell et al. (2008), can be estimated using the following equation:

$$TGR_i = TE_i^* / TE_i \qquad (2)$$

where *TGR* is the technology gap ratio, TE_i^* is the technical efficiency with respect to the meta-frontier, and TE_i is the technical efficiency with respect to the group-frontier. The technical efficiency relative to the meta-frontier is always less than the technical efficiency relative to the group-frontier, thus bounding the *TGR* value between 0 and 1. If the *TGR* value is close to 1, this indicates that a group-specific production frontier is close to the meta-frontier, indicating a more advanced technology level. In contrast, the closer the *TGR* is to 0, the further the group frontier is from the meta-frontier, indicating a less-developed production technology level (see O'Donnell et al. (2008), for details).

2.2 Truncated Regression Analysis

Application of a regression model in a second stage has been widely used to investigate determinants of DEA efficiency measures. In the literature, we find the Tobit regression as the most commonly used approach (Dhungana et al., 2004; Frija et al., 2009; Speelman et al., 2008; Wadud and White, 2000). The use of Tobit regression in a second stage has been justified by the argument that because efficiency scores vary between zero and one, they are censored values. However, McDonald (2009) argued that efficiency scores are not censored but are actually fractional values. Simar and Wilson (2007) noted that conventional approaches to inference in two-stage efficiency are invalid due to i) the complex and unknown serial correlation among estimated efficiencies and ii) the lack of description about the data-generating process. These authors proved that in a second stage, single bootstrap truncated regression performs well. In this study, a single bootstrap truncated regression is used to identify the determinants of groundwater use efficiency. The estimated specification for the regression model is as follows:

$$y_i = \alpha_i + \sum_{i=1}^{n} \beta_i z_i + \varepsilon_i \geq 0; \text{for } i = 1, ..., N$$

and $\varepsilon_i \rightarrow N(0, \sigma^2)$

(3)

where y_i is either technical, cost, allocative or water use efficiency, Z_i is the set of explanatory variables for $i = 1, ..., 12,$ and ε_i is the error term.

3 Data, Variable Definitions and Descriptive Statistics

The study is conducted within two districts, i.e., *Lodhran* from the cotton-wheat region and *Jhang* from the mixed-cropping region of the Punjab province, Pakistan. In the study areas, rural households heavily rely on groundwater as their major source of irrigation because canal water supplies are limited to non-existent in parts of these districts. The canal water contribution for the cotton crop during 2010-11 was observed to range 20-44% of the total irrigation requirement. The study areas in both districts have deep water tables that require high tube-well installation costs. The variation in the bore depth was observed to range between 60 metres and 99 metres in *Lodhran* and from 33 metres to 57 metres in *Jhang*. It has found that due to low water tables and the high installation cost, tube-well population is relatively less dense in *Lodhran* and parts of the *Jhang* district. Therefore, groundwater transactions as under informal markets are more active in *Lodhran* and *Jhang* compared to other districts having shallow water tables. Previously, large farms were often found to be involved in selling groundwater (Meinzen-Dick, 1996; Shah et al., 2008). However, under the given electricity shortage and growing cropping intensities, it has become difficult for large farms to have surplus water supplies. Only medium-size farms or large farms having more than one tube-well are involved in selling groundwater in the study districts, while small subsistent farmers or tenants farmers purchase water for irrigation.

The data used in this study are based on a detailed survey conducted during the *Kharif* season 2010-11 in the *Lodhran* and *Jhang* districts of the Punjab province, Pakistan.
A multi-stage sampling technique was used in data collection. At the first stage, one *tehsil* was selected purposively from each district. In the next stage, 10 villages were selected at random from each purposively selected *tehsil*. In the study areas, a village usually contains of

70-80 household farms. The information about tube-well owners and water buyers were collected with the help of the extension field staff and key informants for the selected villages. Finally, from each village, 5 tube-well owners and 5 water buyers were selected randomly to obtain the differential impact of well ownership and to reveal the difference of amount of water applied and the production gains of tube-well owners and water buyers, thus making a total sample size of 189 groundwater users, i.e., 98 tub-well owners and 91 water buyers.

The data were collected using an interview schedule. During the interview, we collected information on various output and input quantities. The inputs are measured as (1) seed and fertiliser in kg/acre, (2) pesticide and farm operations as number of applications/acre, (3) total labour, consisting of hired (casual and permanent) and family labour in hours/acre, and (5) groundwater use in cubic metres/acre. Cotton yield (output) is measured in kg/acre as well. For different inputs and output quantities, information on their respective price was also collected in Pakistani Rupees. The descriptive statistics of the variables used in the DEA model are presented in Table 1.

[Insert Table 1]

Table 1 compares selected variables used in the DEA analysis. Descriptive statistics show considerable variations in the use of the inputs and output produced by tube-well owners and water buyers. The average farm size of the sample farms is 7.7 acres with average of 9.7 acres for the tube-well owners and 5.5 for the water buyers. All farms in the sample are characterised as farms with a large share of family labour, and there is a considerable variation in the number of hours worked on farms. Overall, the average cotton yield is 831 kg/acre, with a minimum of 480 kg/acre and maximum of 1400 kg/acre. There is also a significant difference in the seed rate, with a mean of 8.3 kg/acre, ranging from 5 to 10 kg/acre. The amount of seed used generally varies because of conventional sowing methods, the time of sowing and the type of variety cultivated. Similarly, there is great variability across the farms in fertiliser and chemical application. In the case of groundwater irrigation, buyers on average use 7% less groundwater than tube-well owners, while they pay, on average 2 times more price to irrigate one acre of cotton crop. The respective prices of the different inputs also show significant variability. On average, the fertiliser, labour, and irrigation cost constitute 70% of the total production cost. The share of the irrigation cost to the total production cost is observed to be between 12% for the tube-well owners while 20% for the water buyers.

The explanatory variables used to explain the efficiency differentials in the second-stage regression include (1) the age of the farmer in years (age-squared was also included to examine the possibility of decreasing return of human capital), (2) farm size in acres, (3) a dummy variable indicating the cropping region, (4) a dummy variable indicating family status, (5) a dummy variable indicating the education level of the farmers, (6) a dummy variable indicating the farm's tenancy status, (7) a dummy variable for variety type, (8) a dummy variable indicating tube-well ownership, (9) a dummy variable indicating access to canal water, (10) a dummy variable for off-farm income activities, (11) a dummy variable for credit or loans for the farm, and (12) a dummy variable indicating access to extension services. Table 2 presents the summary statistics of the explanatory variables.

[Insert Table 2]

The average farmer's age is 44 years, ranging from 25 to 65 years. The rural sociology of the study districts is dominated by the joint family system. Among the sampled farms, approximately 68% of the farming families are living as joint families. The statistics on education clearly reflects a lack of education. It has been observed that 45% of the surveyed farmers have no formal education. Only 21% of the farmers have an education level above matriculation. A significant part of the surveyed farmers cultivate their own land. Only 19.5% of the farmers are tenants. Similarly, only a small proportion of the farms have adopted some kind of agricultural innovations such improved seed varieties and seed treatments etc. Only 28% of the farmers are found to use improved seed for cotton crop. Because farming is a major livelihood activity among rural communities, only a small proportion (16.5%) of the farmers has off-farm income sources. The statistics indicate that region of extension services and agricultural credit is limited in the study areas. Only 24% of the farmers managed to get credit from private banks or public agencies, and 31% of the farmers participated in agricultural training programmes or received advice from the extension field staff.

4 Empirical Results and Discussion

4.1 Technical Efficiencies

The results on the technical efficiencies under meta-frontier and group-frontier specifications are presented in Tables 3. The results indicate that the tube-well owners and water buyers are more technically efficient under group-frontier than the met-frontier. The estimated mean technical efficiency under the meta-frontier is 87% and 86%, respectively, for the tube-well owners and water buyers, which means that a 13% and 14% increase in production is possible with the present state of technology. The mean TE estimates under group-frontier, however, suggest 8% and 12% improvements in TE for the tube-well owners and water buyers. Although, mean TE scores do not indicate substantial technical inefficiencies, nevertheless, only 19% of the tube-well owners and 17% of the water buyers were found to be fully efficiency under the meta-frontier estimates. However, the group-frontier estimates suggest that 38% of tube-well owners and 23% water buyers are fully efficient. Thus, improving technical efficiency can help to improve farm productivity and ultimately farm income.

[Insert Table 3]

Empirical results indicate a gradual improvement in technical efficiency, implying that over the time, technical efficiency among the cotton growers is improving in Pakistan. For example, Abedullah et al. (2006) reported similar 88% mean technical efficiency among large scale cotton growers in Pakistan. However, Hussain et al. (1999) reported 77% technical efficiency estimates among the cotton growers in Pakistan.

4.2 Technology Gap Ratio

As observed from Table 4, the average technology gap ratio (*TGR*) for the water buyers shows that they are operating closer to the meta-frontier than are the tube-well owners.
A difference test with a *p*-value of 0.000 indicates that the technology gap ratio among the tube-well owners and water buyers is statistically significant. On average, the tube-well owners exhibit a technology gap ratio of 0.94 compared to the water buyers 0.98 technology gap ratio. This ratio implies that given the technology potentially available, the tube-well owners at the fixed input endowment exploit, on average, 94% of their potential output, whereas the water buyers achieve 98% of their potential output. In a recent study, Rao et al. (2012) presented a view that in addition to the technological differences, the effect on total productivity might differ if different technological groups are operating at different levels of economies of scale and scope. In this case of groundwater irrigators for cotton in the Punjab, both of the above- mentioned situations, i.e., the tube-well owners and water buyers not only

differ technologically, but they are also operating at substantially different scales of operation.

[Insert Table 4]

4.3 Explaining Efficiency Differentials

The empirical findings concerning the sources of the efficiency differentials among the farms are presented in Table 5. The results indicate that when moving from the cotton-wheat region to the mixed-cropping region, there is not a substantial change in technical efficiency, indicating that cotton producers from both regions are almost equally technical efficient.

[Insert Table 5]

Farmer's age is found to be negatively associated with the level of technical efficiency. It has been argued in the literature that aged farmers are less inclined to adopt new technology and are more sceptical to the extension advice (Speelman et al., 2008). However, there are mixed results for the impact of age on efficiency measures. For example, Karagiannis et al. (2003) found the impact of age to be statistically significant in improving technical efficiency, while Frija et al. (2009) found the impact of age non- significant on technical efficiency.

The positive farm size coefficient indicates that larger farms are more technical efficient than small farms. Much empirical evidences show a positive relationship between the farm size and efficiency measures. For example, Wadud and White (2000) and Balcombe et al. (2008) found a positive relationship between farm size and efficiency. The relationship between family size and technical efficiency indicates that joint families are less efficient than single families. According to (Haji, 2007) large family size and the less attractive off-farm labour wages can contribute towards excessive use of labour on the farm.

The level of education has a positive significant impact on technical efficiency meaning that the education attainment significantly improves the level of farm efficiency. In the literature, however, there found mix results in the literature about the efficiency and education relationship, e.g., Karagiannis et al. (2003) found that degree of technical is positively affected by the level of education. However, Haji (2007) and Speelman et al. (2008) found that education does not affect technical efficiency significantly.

The positive relationship between land ownership and efficiency is intuitive i.e., land owners are more technically efficient than non-owners (Frija et al., 2009; Speelman et al., 2008). The study finds that the adoption of *Bacillus thuringiensis* (*Bt*) cotton significantly improves technical efficiency of the farmers compared to those who cultivated the conventional cotton varieties. The positive (although non-significant) coefficient indicates that owning a tube-well increases technical efficiency.

The study finds that off-farm income is negatively associated with the technical efficiency. This can be attributed to the reason that farmers, who are engaged in off-farm income activities, usually pay less attention to farming activities. Hence, they remain less technically efficient compared to their counterparts. Similar is the case with credit, i.e., those farmers who managed to get credit are more technically efficient than who did not. The findings of Karagiannis et al. (2003) and Haji (2007) also confirm the impact of off-farm income and credit positive in improving technical efficiency of the farms.

Finally, the positive significant impact of extension advice on the technical efficiency confirms the belief that the farmers who tend to seek more extension advice are technically more efficient than those who have less or no contact with extension staff (Parikh and Shah, 1994).

5 Conclusion

This study employed a non-parametric approach (DEA) to estimate production efficiency in cotton farming using a cross-sectional survey of 189 farmers comprising 98 tube-well owners and 91 water buyers in the Punjab province of Pakistan. First, it is observed that there is low level of technical inefficiencies. Secondly, the technical efficiencies are relatively better under the group-frontiers compared with the meta-frontier. The estimated mean technical efficiency under the meta-frontier is 87% and 86%, respectively, for the tube-well owners and water buyers, which means that a 13% and 14% increase in production is possible with the present state of technology. The group frontier estimates suggest 8% and 12% increase in cotton production for the tube-well owners and water buyers respectively. This implies that when tube-well owners and water buyers are estimated under group frontier, they tend to be more technically efficient. On average, the tube-well owners exhibit a technology gap ratio of 0.92 compared to the water buyers 0.88 technology gap ratio, indicating that tube-well owners are operating closer to the meta-frontier than are the water buyers.

Since cotton production in Pakistan is not consistent and yield per hectare is in gradual decline over the past few years. Based on present empirical findings this study recommends cotton productivity in Pakistan can be improved through better farm management practices and efficiency input utilization. To bridge the widening production and consumption gaps, apart from Cotton Vision 2015 national strategy components, a package of policy intervention is needed that will focus on improving the input use efficiency in cotton production. This study suggest that to improve the efficiency of production among cotton growers, efforts and development strategies should be directed towards educating farmers and increased adoption of genetically modified crop varieties. In this regard, extension advice can play a significant role in improving technical efficiency through adoption and diffusion of recent production technology.

Table 1: Descriptive statistics of the variables used in DEA analysis

Variable Definition (unit)	**Mean**	**SD**	**Min.**	**Max.**
Inputs				
Seed/*Acre* (*kilograms*)	8.307	1.31	5	10
Seed cost/ *Acre* (*PKR.*)	2321.27	561.66	1400	4000
Total labour hours/ *Acre*	327.56	53.62	168	465
Total labour cost/ *Acre*	13619.28	2167.65	7000	19375
Fertilizer / *Acre* (*kilograms*)	208.17	60.30	50	450
Fertilizer cost/ *Acre* (*PKR.*)	5261.97	1785.90	1680	14025
Number of chemical applications	6.57	1.36	3	9
Chemical cost/ *Acre* (*PKR.*)	4355.15	1262.93	1600	7200
Number of farm operations	12.48	4.29	3	21
Machinery cost/ *Acre* (*PKR.*)	4004.85	827.63	2200	8000
Irrigation cost/ *Acre* (*PKR.*)	5811.67	2670.93	2232	17587.14
Groundwater volume/ *Acre* (m^3)	2206.70	401.74	1421.75	3210.2
Cropped area in acres	7.68	6.04	1	25
Output				
Cotton yield/acre (kilograms)	831	178.87	480	1400

Table 2: Summary statistics of the variables included in the truncated regression

Demographic Characteristics	**Continuous variables**				**Dummy variables (%)**	
	Mean	SD	Min.	Max.	0	1
Farmers' age (Years)	44	9	25	65		
Farm size (Acres)	11.50	7.60	2	35		
Family status (0= *Single family,* 1=*Joint family*)					32	68
Education in years of schooling (0=*Illiterate,* 1=*Educated*)					45	55
Off-farm income (*0=No,* 1=*Yes*)					83	17
Land tenure status (0=*Tenants,* 1=*Owners*)					20	80
Seed type (0= *Farmer seed,* 1=*Purchased seed*)					75	25
Seed quality (0=*Un-improved,* 1=*Improved*)					72	28
Tube well ownership (0= *Non-owners,* 1=*Owners*)					52	48
Access to canal water (0=*No,* 1=*Yes*)						

Credit access (0=*No,* 1=*Yes*)	76	24
Extension services (0=*No,* 1=*Yes*)	69	31

Table 3: Frequency distribution of technical efficiencies under meta-frontier specification

	Tube-well Owners		**Water Buyers**	
Frequency (%)	**MTE**	**GTE**	**MTE**	**GTE**
<40	0	0	0	0
40-50	0	0	0	0
50-60	0	0	0	0
60-70	5	0	7	4
70-80	21	10	20	15
80-90	23	26	29	29
90-99	30	24	19	21
100	18	38	16	22
Mean	0.869	0.922	0.864	0.883
Std. Dev.	0.104	0.087	0.103	0.099
Minimum	0.646	0.709	0.637	0.638
Maximum	1	1	1	1

Table 4: Average technical efficiency for group frontier and meat-frontiers and technology gap ratio

	GTE	**MTE**	**TGR**
Tube-well owners	0.92	0.87	0.94
Water buyers	0.88	0.86	0.98

Note: GTE, MTE and TGR are group specific technical efficiency, meta-technical efficiency and technology gap ratio

Table 5: Truncated regression results of the factors affecting technical and water use efficiencies

Explanatory Variables	**Technical efficiency**	
	Coefficient	**SE**
Cropping region (0= *Cotton-wheat,* 1=*Mixed-cropping region*)	.0089	.0179
Farmer's age (*Years*)		
Age	-.0072	.0048
Age^2	.0000*	.0001
Cropped area (*Acres*)	.0004	.0009
Family status (0= *Single,* 1= *Joint family*)	-.0112	.0122
Education dummy (0= *Illiterate,* 1= *Educated*)	.0683***	.0187
Land tenure status dummy (0= *Tenants,* 1=*Owners*)	.0072	.0146
Type of variety (0=*Upland American,* 1= *Bacillus thuringiensis (Bt)*	.1318***	.0114
Tube well ownership dummy (0=*Water buyers,* 1=*Tube-well owners*)	.0069	.0141
Off-farm income (0=*No*, 1=*Yes*)	-.0093	.0144
Access to canal water (0=*No*, 1=*Yes*)	.0106	.0186
Credit dummy (0=*No*, 1=*Yes*)	-.0021	.0125
Extension services dummy (0=*No*, 1=*Yes*)	.0376***	.0117
Constant	.9049***	.1085
Log likelihood	248.55	

Note: *, **, *** indicate significance at 10%, 5% and 1% respectively. Number of bootstraps=4000

References

Abedullah, Kouser, S., Mushtaq, K., Mazhar, M., 2006. Role of credit to enhance cotton production in Punjab, Pakistan. Pakistan Journal of Agricultural Sciences 43, 197-205.

Ahmad, M., Chaudhry, G.M., Iqbal, M., 2002. Wheat productivity, efficiency and sustainability: A stochastic frontier analysis Pakistan Development Review 41 643-666.

Alene, A.D., Zeller, M., 2005. Technology adoption and farmer efficiency in multiple crops production in eastern Ethiopia: a comparison of parametric and nonparametric distance functions. Agricultural Economics Review 6, 5-17.

Balcombe, K., Fraser, I., Latruffe, L., Rahman, M., Smith, L., 2008. An application of the DEA double bootstrap to examine sources of efficiency in Bangladesh rice farming. Applied Economics 40, 1919-1925.

Banker, R.D., Charnes, A., Cooper, W.W., 1984. Some models for the estimation of technical and scale inefficiencies in Data Envelopment Analysis. Management Science 30, 1078-1092.

Battese, G., Rao, D.S.P., O'Donnell, C., 2004. A Metafrontier Production Function for Estimation of Technical Efficiencies and Technology Gaps for Firms Operating Under Different Technologies. Journal of Productivity Analysis 21, 91-103.

Battese, G.E., Rao, D.S.P., 2002. Technology gap, efficiency, and a stochastic metafrontier function. International Journal of Business and Economics 1, 87-93.

Dhungana, B.R., Nuthall, P.L., Nartea, G.V., 2004. Measuring the economic inefficiency of Nepalese rice farms using data envelopment analysis. Australian Journal of Agricultural and Resource Economics 48, 347-369.

FAO, 2012. FAOSTAT. [Online]. Food and Agriculture Organization of United Nations (2012). http://faostat.fao.org/site/339/default.aspx. Accessed date 19 December 2012.

Frija, A., Chebil, A., Speelman, S., Buysse, J., Van Huylenbroeck, G., 2009. Water use and technical efficiencies in horticultural greenhouses in Tunisia. Agricultural Water Management 96, 1509-1516.

Haji, J., 2007. Production Efficiency of Smallholders' Vegetable-dominated Mixed Farming System in Eastern Ethiopia: A Non-Parametric Approach. Journal of African Economies 16, 1-27.

Hussain, M.S., Coelli, T., Simmons, P., 1999. An analysis of the technical efficiency of cotton farmers in the Punjab province in Pakistan, Annual AARES Conference, Christchurch Convention Centre Christchurch, New Zealand.

Kalyan Chakraborty, Sukant Misra, Johnson, P., 2002. Cotton farmers' technical efficiency: Stochastic and nonstochasticnproduction function approaches. Agricultural and Resource Economics Review 31, 211-220.

Karagiannis, G., Tzouvelekas, V., Xepapadeas, A., 2003. Measuring Irrigation Water Efficiency with a Stochastic Production Frontier. Environmental and Resource Economics 26, 57-72.

Khan, M.A., Iqbal, M., 2005. Sustainable cotton production through skill development among farmers: Evidence from Khairpur District of Sindh, Pakistan. The Pakistan Development Review 44, 695-716.

McDonald, J., 2009. Using least squares and tobit in second stage DEA efficiency analyses. European Journal of Operational Research 197, 792-798.

Meinzen-Dick, R.S., 1996. Groundwater markets in Pakistan: participation and productivity. International Food Policy Research Institute, Washington, DC, USA.

O'Donnell, C.J., Rao, D.S.P., Battese, G.E., 2008. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empirical Economics 34, 231–255.

Pakistan, G.o., 2011-12. Economic Survey of Pakistan. Finance Division, Ministry of Food and Agriculture., Islamabad, Pakistan.

Parikh, A., Shah, K., 1994. Measurement of technical efficiency in the NOrth-West Frontier Province of Pakistan. Journal of Agricultural Economics 45, 132-138.

PCCC, 2008. Pakistan Central Cotton Committee. Annual Progress Report of Central Cotton Research Institute 2007–08. Multan, Pakistan.

Rao, E.J.O., Brümmer, B., Qaim, M., 2012. Farmer Participation in Supermarket Channels, Production Technology, and Efficiency: The Case of Vegetables in Kenya. American Journal of Agricultural Economics.

Shafiq, M., Rehman, T., 2000. The extent of resource use inefficiencies in cotton production in Pakistan's Punjab: an application of Data Envelopment Analysis. Agricultural Economics 22, 321-330.

Shah, T., Bhatt, S., Shah, R.K., Talati, J., 2008. Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India. Agricultural Water Management 95, 1233-1242.

Simar, L., Wilson, P.W., 2007. Estimation and inference in two-stage, semi-parametric models of production processes. Journal of Econometrics 136, 31-64.

Speelman, S., D'Haese, M., Buysse, J., D'Haese, L., 2008. A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa. Agricultural Systems 98, 31-39.

Thiam, A., Bravo-Ureta, B.E., Rivas, T.E., 2001. Technical efficiency in developing country agriculture: a meta-analysis. Agricultural Economics 25, 235-243.

USDA, 2012. United States Development Agency (2012). http://www.usda.gov/wps/portal/usda/usdahome. Accessed 20 December 2012.

Wadud, A., White, B., 2000. Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. Applied Economics 32, 1665-1673.